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Trialling the SMART Approach: Identifying and Assessing Sense-making

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Abstract

It is important to develop tools that support sense-making by providing representations that help to capture the externalisation of the thinking process. The paper focuses on a new method for identifying the sense-making processes of experts by combining probes with cognitive task analysis methods. The data-frame sense-making model is used as a theoretical frame, and the probes have been developed around the model to elicit experts' sense-making. However, in the analysis proceeding a sense-making task, the developed probes by themselves were unable to capture the experts sense-making and a stronger emphasis of cognitive task analysis methods and observations were required to interpret the findings.

Keywords

Data-frame sense-making model, SMART probes, CDM, Sense-making, Cognitive Task Analysis.

INTRODUCTION

The purpose of this paper is to report findings from the trial of a new method for identifying and assessing the occurrence of sense-making activities during the complex information analysis and sense-making tasks. For example, the process of preparing a literature review. The new method we propose is what we refer to as SMART (Sense-Making And Reasoning assessment Tool) probes. This study partly stems from a question that asks, "How do we measure insight?" as a gauge of success in interactive visual sense-making systems. It is part of our research that has been funded to investigate how we should design the visual supports for the human analytical reasoning process.

In particular, how the visual supports in a computer user interface should be designed so that it is compatible with the way investigators or analysts reason, and how they assemble data to create plausible stories or narratives that can provide explanations of what they have discovered and how they have used the data (or evidence) to construct their conclusions or claims. We hope to uncover the process of sense-making such that we might be able to explain how they arrive at initial or tentative guesses and how they mature these explanations into robust arguments that can withstand the rigours of interrogation.

Grounded in the Data-Frame Model (DFM) (Klein, Phillips, Rall, & Peluso, 2007), SMART is a cognitive task analysis (CTA) technique, designed for use in a combination of observation study and process tracing. For recall-assisted retrospective in-depth interview see Cooke (1994). We set the participants a set of sense-making tasks, and in this case, a task commonly associated with the literature review process – finding the most significant authors in a particular subject area. We observe and record librarians carrying out the task. At the end of the task, we ask the participants a specific set of probes to elicit their accounts of actions and reasoning what occurred during the task. The probes ask questions about various aspects of sense-making as described by the DFM.

The probes were designed partly based on our familiarity with another well-known CTA method: Critical Decision Method (Klein, Calderwood, & MacGregor, 1989).

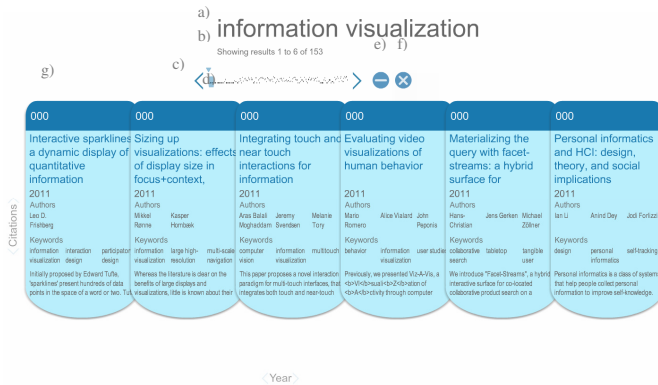
However, given that there are unlikely to be critical incidents in the sense-making of a literature review task, we developed a set of probes that was planned to prompt the participants to introspect on their recent experience in finding the information (rather than the actions of searching and retrieving, but the considerations and thinking about why one piece of information became an anchor or a point of leverage to locate further information), assembling them, creating tentative explanations for what they have found, reviewing and revising, reformulating their explanations and even discarding them. Then guided by the DFM, we coded the findings in terms of the various connect, elaborate, question and reframe elements provided by the model.

It should also be noted that SMART was used in the context of a prototype system with a non-traditional GUI (graphical user interface) we call INVISQUE, which stands for Interactive Visual Search and Query Environment (Wong, Chen, Kodagoda, Rooney, & Xu, 2011) (see Figure 1). Information entities were represented as individual index cards, mimicking the library environment. In our study, the index cards contained information about journal or conference articles. These index cards could be freely moved around the interface, organised, re-grouped, set aside, as well as automating tedious manual operations, such as sorting the cards along the x-y axes by year of publication or by the number of citations; or to have the system locate the common papers between two groups of index cards – a Boolean operation – by simply dragging one group of cards on to the other. The design itself is guided by principles such as visual cues and affordances, cognitive load theory, focus + context, and Gestalt principles of perception. These techniques can be incorporated yet keeping the system simple and learnable by empowering good interface design principles and heuristics (Nielsen, 2007; Norman, 1988).

The objectives for this study are fourfold: (i) Can SMART be used to uncover the process of sense-making in a literature review type of task? (ii) What are the limitations of using SMART in this way? (iii) How would our findings be used to help us understand how people construct explanations or narratives? While important, this paper will not address the issue of whether the sense-making activities we identify can be considered surrogate aspects of *insight*. Instead, in this study we wanted to know if we could identify sense-making activities. This would then be developed further in future

studies to ascertain whether which elements of sense-making can be used as surrogate measures for “insight”; and finally (iv) In what ways do the external representation of our thinking and reasoning in the literature review task support or hinder sense-making?

Figure 1. Invisque showing results for information visualization. a) search term; b) quick overview of the results; c) scatter plot - which represents each publication by a dot, the height and order of the dot depends on how the information has been ordered in x-y axis, d) data interval window - which highlights the number of results shown in detail; e) cluster minimize button; f) cluster close button; g) results shown in detail using index cards - the index cards are organized by year (x-axis) and citations (y-axis); h) information drill down icon; i) an index card in focus - icon top left to right: number of citations, move the index card out of the cluster, drill down to the publication, drill down to the references, icon bottom left to right: save, make an annotation, delete; j) index card already viewed.



SENSE-MAKING

In this section, we provide a brief overview of sense-making, starting with the Data-Frame Model of sense-making (Klein et al., 2007), and the implications this model has for the design of visual analytics systems that are typically developed to assist in making sense of large volumes of data. According to Klein (2007) sense-making takes place when faced with ambiguity or unfamiliar situations or inadequacy of their current understanding of a situation. Here one explores possible relationships (e.g. between people, places and events etc.) to gain awareness of the situation. Klein suggests there is no clear start or end point to where sense-making beginnings and ends. He further describes that sense-making has two distinct processes, either data being fitted on to a frame (mental model), or fitting the frame around the data. The DFM comprises of four main sense-making processes: *Connect with the frame* is said to occur when the presented data is understood within the context of a frame, an initial and possibly tentative understanding of data representing a given situation; *Elaborate the frame* is the process of searching for more data that might extend one's understanding of the situation. As one understands the situation better, one is able to ask more questions of it; *Question the frame* is said to occur when one asks questions about the validity or the assumptions made about one's current understanding or frame; and a *Re-frame* occurs when one realises that one has misunderstood what the data really means. There are other sub-processes such as preserving the frame, comparing and seeking the frame in the DFM. The frame is a mental construct that describes how we position our knowledge in relation to the new data we

receive and are starting to understand. This frame is a way to conceptualise how we organise our understanding of the new data in relation to what we already know. This new organisation represents a new understanding, and when this new understanding is something significant or meaningful, it represents the moment of insight - this unique organisation of knowledge and information "... that places the full set of clues in a unique explanatory perspective" (Lonergan, 1957). Therefore, it is with this that we developed SMART to identify sense-making activities, and to trace how they lead to the assembly of data. The INVISQUE prototype enabled users to create external representations of their thinking processes, which we then used as a surrogate for understanding when insight has been attained.

In domains such as security and military intelligence, much of the data tends to be uncertain and ambiguous, whereas in domains such as medical and health, there is greater certainty in patient records. However, while dissimilar in this respect, the cognitive strategies invoked during human sense-making in either domain have much in common. At the same time, we are also conscious of Weick's (Weick, 1995) realisation that sense-making differs from interpretation. In the literature review task in our study, participants were observed to do more than search and retrieve. They also attempted to construct meaning by filtering, framing, creating facts, or anchors, from which they can launch further enquiries. They were creating an understanding. This is very much in line with Klein's et al.'s definition of the outcome of the sense-making process, in which a frame is a structured, supported explanation, which guides the search for more data.

Although the Pirolli and Card (2005) model of intelligence analysis has been frequently cited, and useful in describing the stages by which data and analysts' observations are processed and eventually transposed into 'hypotheses' to generate suitable answers. As with most models, however, is not without its shortcomings. For our purposes, this is inadequate for describing the strategies used at each stage of the intelligence process, e.g. how are hypotheses formulated? We suggest that the Data-Frame Model can provide an alternative. It describes an interacting set of strategies that people use when making sense of a situation. We can apply this to the information analysis and representation design context, which can also be helpful in deriving criteria for assessing the effectiveness of designs for systems supporting sense-making activities.

VISUAL SUPPORTS FOR SENSE-MAKING: UNDERSTANDING WHAT TO REPRESENT

Visualisations are commonly used to communicate meaning. However, very often what is meant is seldom obvious, and requires some degree of explanation before the intended meaning is understandable. How do we help a viewer see and understand what the data contains? How do we help the viewer *connect* with the data, be aware that there is more from which they must *elaborate*? Or be conscious that, perhaps, something does not look right and so to *question* what he/she is seeing? Or be brought to the realisation that somehow their assumptions have been wrong and therefore

should re-consider their conclusions, and *reframe* their perspective and understanding of the data? We believe these four aspects of Klein et al.’s DFM can guide our thinking on how we design visual supports for representing the sense-making process.

Knowing what to visually represent at the user interface is partly governed by a principle known as the Law of Requisite Variety. The Law states that a system should have the capabilities to cater for the variety of situations that the system will face. Failure to comply with this law in causal systems such as a nuclear power plant, have led to problems of “brittle systems”. These systems fail to cope when the situations fall outside the conditions that it was planned to cope with. Unlike the process control systems that are governed by the laws of nature, the systems used by intelligence and investigative analysts, are governed by the principles of logic and human analytical reasoning.

In the same way that cognitive work analysis can provide visual supports (e.g. Ecological Interface Design) for the human operator of a physical process control system, we intend SMART will help us identify the structure and processes that need to represent the “thinking processes”. Our challenge might be how to visually represent these “thinking processes” such that we can trace our reasoning through the thinking space. This is our initial tentative steps. Table 1 summarises the SMART probes identified and their relationship to the DFM.

Table 1. DFM sense-making strategies and SMART probes.

DFM Sense-making Strategies	Probes
Connecting data and Frame	Q1. In what ways does the system help you in seeing or discovering patterns in the data? Q2. In what ways does the system help you base your discovery/ identify an influential author? Q3. In what ways does the system aid you in constructing stories to account for the observed data? Q4. In what ways does the system help you to identify what data is related to the potential influential author your identifying?
Elaborating the frame	Q5. In what ways does the system help/ hinder you discovering more or other relevant details, fill in slots?
Questioning the frame	Q6. In what ways does the system help or hinder your ability to determine if something is not right with the data? Q7. In what ways does the system help you realise that there is a mis-match between the data your presented with and your expectation you had for the influential author?
Preserving the frame	Q8. In what ways does the system support you to make the decision to keep the influential author you considered? Same Q9. In what ways does the system support to tell a story or a narration in a way that you feel is adequate?
Comparing frame	Q10. In what ways does the system support you to compare patterns in the potential influential author you considered? Q11. In what ways does the system support you to compare and see gaps in the influential author you considered?
Seeking a frame	Q12. In what ways does the system support you to provide reasons for seeking another influential author?
Re-framing	Q13. In what ways does the system support you to

question the influential author you considered?

Q14. In what ways does the system support you to find alternatives to question the basis of your considerations made to consider an author as influential?

EVALUATION

The aim of the investigation was to use SMART probes and other CTA methods to capture experts’ (librarians) sense-making processes when presented with an ill-defined problem that they addressed using the INVISQUE system. The primary purpose of the study was to explore whether INVISQUE supported sense-making by incorporating design features such as the sorting, organising, reorganising of data; performing multiple searches; pan and zoom an infinite canvas; performing Boolean operations (such as AND and OR) to further filterer information; and visual cues that distinguish which data items have been saved, viewed or deleted. A secondary outcome of the study was an assessment of the SMART probes (see Table 1), that were used to elicit the expert’s sense-making processes.

METHOD

Six participants who were librarians of the university volunteered for the study. They comprised of three females and three males with an average age of 43 years. None of the participants had used the Invisque interface previously, although all the participants were competent computer and library database system users.

SMART probes along with multiple Cognitive Task Analysis (CTA) methods were used to extract and understand the participants’ cognitive process during the task. The CTA methods used were think-aloud, semi-structured interview techniques along with user observations. Screen capture, audio recording and detail user interface interaction transaction logs were captured and stored in the local machine. These were then later analysed using thematic analysis to understand the user sense-making process.

Procedure

The Special Interest Group on Computer–Human Interaction conference (SIGCHI) proceedings from 1982 to 2011 amounting to approximately 9000 publications were provided as the dataset. This meta-data (publication, title, authors, keywords, abstract, citation) were linked into Invisque and publications were linked to the ACM digital library via the university’s Athens access. The area of *information visualization* within the SIGCHI was selected due to the small sample size, while still comprehensively covering prominent authors. As the task focus relied on understanding the cognitive process the librarians took to address an ill-defined problem aided by Invisque, the following ill-defined problem presented to participants:

We would like you to find influential authors who have made considerable contributions to the field of information visualisation and why? (find a minimum of 3 authors).

Participants were given instructions about the study, and were shown a 15-minute video capturing the functionality of the system. They were informed that there were no right answers and that the study focused on capturing their

reasoning process to address the problem. Participants were given about an hour to complete the task, and were asked to only use the Invisque interface. They were given time to familiarise themselves with the interface and the use of think-aloud protocol. The participants were asked to notify the facilitator when the task was completed. This was followed by a semi-structured interview that lasted for approximately half an hour, which included the SMART probes. The facilitator played back the videos to the participants to make it easier for them to recall the incident and explain their actions, behaviour, decisions or thoughts and avoid any confusion.

RESULTS

This section reports finding identified during the DFMs' connect stage during the initial stages of the participants' data explorations followed by a case study taken of a participant to show the sense-making process taken to determine an influential author.

Exploring the data-frame model's connect stage at the initial stage of the investigation

The table 2 summarises participant's initial stages of the investigation which captures sense-making using the DFMs' connect stage. Results suggest that the system assisted participants in discovering patterns in the data. Specifically they explained that the ability to order information by changing the x and y axes by data elements such as citation and year were useful visual cues when attempting to identify patterns and discover important information.

Author, keyword and title data elements did not provide any visual advantage due to implementation problems. However, participants explained they were quickly able to find the highly cited paper and its authors. This is by highlighting an author name where they were able to observe the author's frequency of publications using scatter plot (relevant publications marked red).

During the initial stages of the evaluation, participants considered highly cited publications and high publication numbers as justification for the level of influence an author may have in their research field (known as anchors). In this respect, participants used system-based patterns to investigate this information such as the height of the index card corresponding to highly cited papers, and their publication numbers represented by the scatter plots red dots.

The participants were able to tell a story about the authors they considered influential by sorting, rearranging, filtering information and observing the patterns in the visualisation (by different views). For example, exploring highly cited publications and identifying authors who made contributions to those publications, next exploring or drilling down to identify other publications made by that author and assessing the influence of those publications (citation) by observing the scatter plot. Then may be identifying how closely related those publications are to the area of research.

However, one drawback was that participants observed that in some cases the keywords were not available to them (missing meta-data due to unavailability), so there was no indicator to show how closely the publication was related to the area of research. None of the participants were seen

drilling down to the publication enabling them to determine if the publication was related to 'information visualisation'.

Most actions are exploratory in nature. From our observations, we identified four cues that were critical to create a starting point for understanding the data at the connect stage, which were patterns, anchors, story construction, and the discovery of other relevant data.

Table 2. Participants' quotes showing how sense-making takes place in the DFM sense-making strategies connect the data to the frame stage based on the SMART probes.

<i>Connect data to the frame</i>	<i>Participants' quotes</i>
<i>patterns in the data</i>	<p>a) Ability to order information by x and y axis: <i>...throughout I was trying to see different views... to see if it was going to show different patterns... (p2),</i> e.g. Citation: <i>...I like the way it stacks it in order of citation, it is nice and visual the way the highest cited paper is kind of higher up...(p1);</i> e.g. Year: <i>...high citations is the fact I am looking for but if I can find someone with equal citations with recent work(p3);</i></p> <p>b) Distribution of author publication frequency: <i>...the red dots to get a sense of how many results do I get for this person...(p1),</i></p> <p>c) Index card information: <i>...his publication with 99 citations was published in 2005 (p1).</i></p>
<i>anchors</i>	<i>...I could ask questions such as what is the highest cited paper, who are the authors who wrote it? Then lets presume at the end of the day if they have produced the highest cited papers there must be something about them which is interesting. I can start to pursue this author (p1)</i>
<i>story construction</i>	<i>...not only did I look at the first and second search results and scanned, and I saw Peter Pirolli keeps coming up and I also looked at the top 6 citations then I went into the direct article. So I organised the data by citation and scanned but focused on the new publications. Looked at the authors then scanned through the first six to see if there were any repeating names, Peter who came up twice and Stuart came up twice so assumed hopefully they were influential (p2)</i>
<i>discover related data</i>	<i>...there was no rating there about relevance to the search term (p4)</i>

Sense-making stages when identifying a potential influential author

In order to show how participants narrowed down influential authors, a case study of a participant (p1) is considered (see Table 3). The participant narrows down Stuart Card as a potentially influential author, who wrote a highly cited publication (patterns). To further explore this initial assumption, the participant highlights the author's name (Stuart Card) and inspects the scatter plot (each dot represents a publication), which provides additional information via a series of red dots (patterns). These observable patterns are called anchors assisting participants to determine if the author could be considered influential.

The participant initiates a new search for the author (by highlighting and dragging the authors name on to the Invisque open canvas) creating a new frame. The participant observes the new frame holds the entire publication (by observing title, keywords, and abstract in some cases) for the

author. Since the participant is only interested in identifying publications for 'Stuart Card' in the field of 'information visualisation', the participant performs a Boolean AND operation (as a way of elaborating the frame and filling information slots).

The participant is now able to construct a story about 'Stuart Card' that he has nine publications in the field of information visualization, which has been published from 1991 to 2009. While exploring the information the participant identifies a publication in 1994 which has 144 citations. He raises concerns about his initial assumption, if Stuart Card is still an influential author. The participant explains, an author could have published a highly cited paper at the start of his/her career but subsequent publications may have not been that influential. To explore this, the participant explores newer publications with high citations. Once the participant reorganised the information and identified that Stuart Card has recent publications (e.g. 2005) which has high citations (e.g. 99), he confirmed that Stuart Card is likely to be an influential author.

Four out of the six participants went on to explain the way information was displayed and the way they were able to engage with the information resulted in observing patterns, that either assisted questioning or strengthening or weakening their initial assumptions. Whereas, the conventional database systems they were used to had no provision for identifying patterns.

Participants were seen moving between initial discoveries of influential authors through to more formalised discoveries. Using SMART we tried to capture how the sense-making processes moved through the DFMs' connect stage, elaborate, and then questioning the frame. However, SMART was unable to make clear distinctions (between the different strategies of the DFM sense-making model).

Table 3. Participant (p1)s' quotes showing how sense-making takes place in the DFM sense-making strategies when identifying a potential author.

DFM sense-making strategies	Participant (p1) quotes
patterns (connecting the data to the frame)	User exploring a highly cited paper which has 144 citations. Which has been published by Ramana Rao and Stuart Card ... when I highlight Stuart Card the little dots (scatter plot which shows many there shows many... so I am looking at Stuart Card and going ah ha... so there are more results here and it is interesting... he (Stuart Card) is beginning to impress me...
anchors (connecting the data to the frame) There are two things a) he was in the highest cited paper, so that gets me to think, ok there is something credible here... then I am seeing a reasonable amount of red dots to suggest that there is a reasonable track record of publications... So those two things indicate this is someone worth putting in the list...
creating the new frame	...if I put Stuart Card as a separate Stuart Card search,...
related (connecting the data to the frame)	... but then of cause it is going to give me all of Stuart Cards papers, it is not giving me the stuff in information visualization...
discovering more or other relevant detail to	...so I am having to recombine Stuart Card and information visualization...

fill slots (elaborate the frame)	
story construction (connecting the data to the frame) OR discovering more or other relevant detail to fill slots (elaborate the frame)	... he has published 9 papers on Information Visualization. So they range from 1991 – 2009.
something might not be right with the data (question his frame)	...there is one publication with 144 (citation)... you could get how someone has a brilliant paper at the start of their career and nothing since...
story construction (connecting the data to the frame)	... if that 99 (citation) paper hadn't been there, you might start saying he got lucky in one occasion in 1994, and the rest of it don't know. That's the other thing that paper was in 1994, his 99 paper in 2005 he has done ok...

DISCUSSION & CONCLUSIONS

We found that the sense-making processes do not have clear boundaries, but instead demonstrate a considerable amount of overlap. Unfortunately, the SMART probes have a low resolution that is only able to discern very broad differences and is not able to detect fine details that might be able to make fine distinctions between the sense-making processes by itself. The notion that the frames are unique assemblies of data to explain, and that the data created changes state from being used as an information search and retrieval and foraging tool, to one that is used as an external representation of one's schemata that evolves as one understands what the data is about. After several iterations, the participants assemble the data in a way that enables them to provide an explanation, thereby creating a frame.

The findings suggest that Invisque offers 'seamless transition' between foraging and sense-making, particularly given the way the two iteratively interweave in practice. A future study could explore if natural sense-making processes are more efficient with systems that lack boundaries and structure.

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